The Cooperative Crab

by Graham Berry

A cooperative crab, with three brains and astigmatic periscope eyes on long stalks, is making major contributions at Caltech toward a better understanding of the central nervous system.

Dr. C. A. G. Wiersma, professor of biology, started research with the crab last summer at the University of Hawaii's Waikiki Marine Laboratory, with Dr. Talbot H. Waterman, professor of comparative physiology at Yale University; and Dr. Brian M. H. Bush, visiting post-doctoral fellow from Cambridge University, England. The study is supported by the National Science Foundation and the National Institutes of Health.

The unusual way in which this crab, *Podophthalmus vigil,* is built, plus the comparative simplicity of its nerve structure, make it invaluable for the investigation of the central nervous system. A native of Hawaiian waters, the crab is only about six or seven inches wide and three or four inches long. Its eyes are set on top of exoskeletal stalks about two inches long. For protection, the antenna-like stalks may be folded back into an indentation in the shell. A small brain is located directly behind each eye. These little brains are computers. Nerve trunks enclosed in the exoskeletal stalks link each "optic brain" with each other and with the larger central brain under the main body shield, or carapace.

How the brains work

The two small brains evaluate the data from the eyes and then pass the evaluated information on to the central brain and to each other. It may be that they are able to bring almost instantaneously into action muscles that are used in running or evasive action.

Of great advantage to biologists is the fact that the optic nerve of this crab contains only about one or two thousand individual nerve fibers, or interneurons —compared with about one million fibers on the human optic nerve. Because most animals of similar complexity have a great many more such optic fibers, the task of learning from them about the central nervous system is much more formidable.

The reason the crab's optic nerve contains comparatively few individual interneurons is that the information received by the eye does not go directly to the larger central brain for evaluation, but travels a very short distance to the so-called optic brain. Here, many steps in the evaluation of the information are carried out. Afterwards, the impulses are sent on to the central brain and to the other eye. Since the optic brain has analyzed the incoming optic signals to a large extent, the evaluated data can be carried by many fewer nerve fibers.

There is at least one biological advantage in having a special brain directly back of each eye—as all crustaceans with good vision have. To get detailed information from the eye to the brain many nerve fibers are required and therefore they must be thin. The thinness offers resistance to the electrical nerve impulses, slowing them down. As a result, the information reaches the brain only after a considerable delay. With a brain near the eye, the many impulses from the eye need travel only a short distance before they reach the optic brain for evaluation. From there to the central brain, or to other parts of the nervous system, fewer evaluated impulses are sent over larger fibers, enabling the impulses to travel much faster.

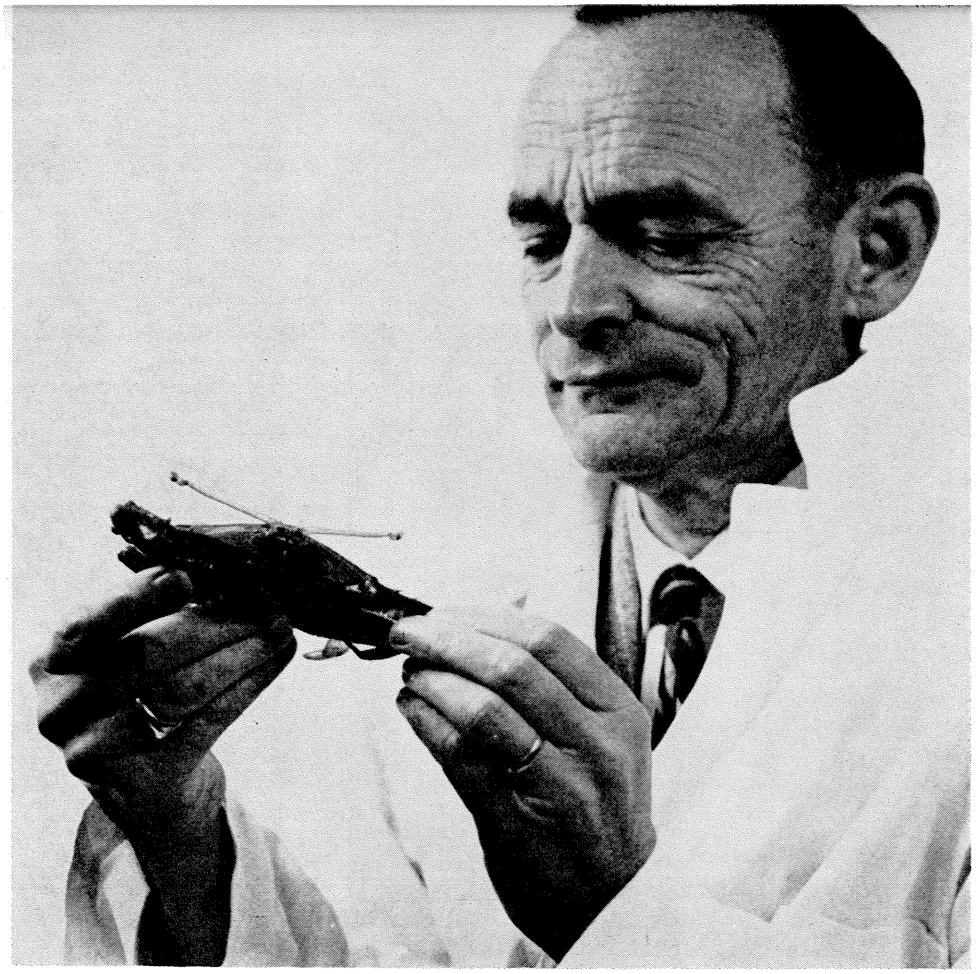
The way to do it

"If you want eyes to be located at a considerable distance from the brain," says Dr. Wiersma, "this is the way to do it." Even so, having one's eyes on the end of long stalks is a rather precarious business, although it can be handy when the crab wants to rest under the mud and still see what's going on.

Because of its shape, the eye must be very astigmatic. Being on the end of a stalk, it has a tremendous range of vision and can see just about everything in its vicinity.

It is the optic nerve of the crab, available as it is in a comparatively long, exoskeletal, insulated sheath, that Dr. Wiersma uses in his research. With delicate and precise techniques which he has developed in years of work on the nervous system of the crayfish, he removes a small segment of the exoskeleton from the eye stalk, exposing the optic nerve trunk. Observing through a binocular microscope, he taps individual nerve fibers with micro-electrodes and records electric nerve impulses that have been stimulated by placing and by moving objects in front of the eye.

These nerve impulses are "waves" of electrical disturbance that move swiftly down the nerve path. The impulses all have about one-tenth volt of energy and



Dr. C. A. G. Wiersma, Caltech professor of biology, and Podophthalmus vigil.

the impulses occur at the rate of 5 to 200 per second. This is the language by which nerves talk. The effect at the receiving end is proportional to the number of impulses.

Dr. Wiersma and his colleagues have discovered three different kinds of optic nerve fibers, or interneurons that react to moving objects. He believes there are several more kinds, some responding to stationary objects. Each of the three "movement fibers" carries a different kind of electrical response to eye stimulation.

One type of interneuron fires (carries electrical nerve impulses) when an object is moved rapidly past the eye. A second kind of interneuron fires only when an object is moved with average speed past the eye. And the third type fires only when an object moves slowly past the eye. These interneurons will fire bursts of impulses only when the kind of eye stimulation is specific to them; otherwise they give only a few scattered impulses which are of little importance to the brain.

Strangely, interneurons of types 1 and 3 will not fire such bursts again for perhaps a minute after the first stimulation, unless the stimulating movement passes the eye in a different direction than the first time.

As for the second kind of interneuron, which apparently is not affected by the same type of inhibition, but continues to fire bursts of impulses as long as objects are moved at medium speeds past the eye, this may give rise to what is called an optic kinetic reflex in which the crab can turn its eyes or even its whole body to follow another animal in its vicinity.

All three kinds of signals are generally independent of the amount of background light, the biologists have found. This is understandable because the crab must be able to react very similarly whether he is in bright or dimly-lit surroundings.

In one series of experiments it was noted that if the eye observes a small object, certain interneurons will fire, but if a larger object then is moved into the place of the smaller one, this interneuron doesn't fire. Apparently the interneuron that has observed the small object now is inhibited by nearby optic fibers.

Does the human optic nervous system operate the way the crab's does? Dr. Wiersma believes it may, pointing out that there is no evidence to the contrary. As with the crab, impulses from the eyes of higher animals probably reach nerve centers along the way to the brain where similar types of preliminary evaluating are carried out, so that different aspects of the visual surroundings are thrown into different nerve channels.

Dr. Wiersma plans to continue to work with the crab, with the idea that a better understanding of its simpler central nervous system will shed light on the operation of the central nervous system of more complex creatures, such as humans.